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Novel mmWave MIMO Radar System Using AWR Software

Key Challenges

Designers at VTT Technical Research Centre of Finland Ltd. (VTT) were tasked with developing a 60GHz frequency-modulated continuous wave (FMCW), frequency-division multiplexing (FDM), multiple-in-multiple-out (MIMO) radar system for short-range, high-resolution detection of nearby moving objects when the radar itself might be moving, in order to capture the flow of people, drones, and other autonomous systems. In addition, the system supports simultaneous localization and mapping, object detection, and remote multi-target vital sign measurements for medical applications. An FDM MIMO architecture was chosen to address the technical requirements for fast imaging and high resolution of multiple targets. Using MIMO techniques, 64 virtual channels were synthesized with only eight RX and eight TX channels (Figure 1), thereby significantly reducing the number of physical elements. This greatly reduces the system complexity, size, and cost.

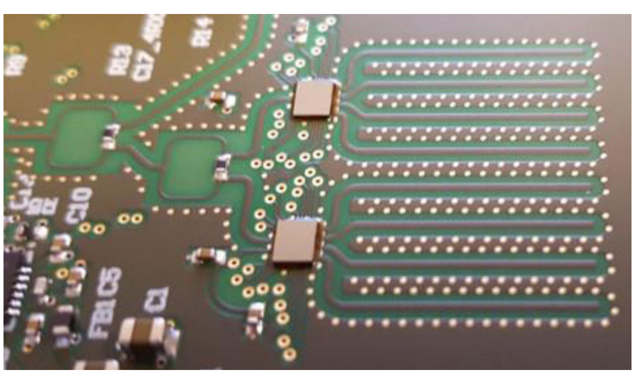

Figure 1: 8 RX channels with 2 RX chips flip-chip mounted on a PCB

Application

- Radar

Software

- Cadence® AWR Design Environment® Software Portfolio, including:
  - Cadence AWR® Visual System Simulator™ (VSS) System Design Software
  - Cadence AWR Microwave Office® Circuit Design Software
  - Cadence AWR AXIEM® 3D Planar Electromagnetic (EM) Analysis

Benefits

- Ease of use
- Simulation speed
- Technical support

In addition, FDM allows accurate phase measurements supporting medical applications such as remote monitoring of heartbeat and breathing rates from the detection of small movements of the chest. Requirements for the radar system included fast imaging >200Hz, range resolution <5cm, multitarget acquisition, moving target capability, and high sensitivity to micromotion, all in a small, lightweight, low-cost footprint. The key challenge for the design was system feasibility, which were studied using AWR VSS software. The actual chip design was made possible through simulation with AWR Microwave Office software using the IHP foundry silicon germanium (SiGe) process design kit (PDK) and EM verification of the on-chip passive components.

The specifications for the system were:

- 1.5° angle resolution with 8TX - 8RX MIMO
- 3-5cm range resolution
- 160° horizontal field of vision (FoV)
- 25° elevation FoV (3D systems with 160° x 160° FoV are also available)

Solution

VTT designers used AWR Design Environment software for this project. A simple diagram of the system implemented in AWR VSS software is illustrated in Figure 2. The signal source is divided between the transmit and receive sides and details of the transmitter power amplifier (PA) and receiver low-noise amplifier (LNA) chains (not shown) can be further developed with results from AWR Microwave Office software co-simulations. The transmitter and receiver signal paths must be well-isolated to operate properly, which impacts certain design aspects and limits the acceptable transmit power level. Otherwise, power from the transmit side will leak into the receiver circuit, potentially saturating the LNA and/or down-conversion mixer.

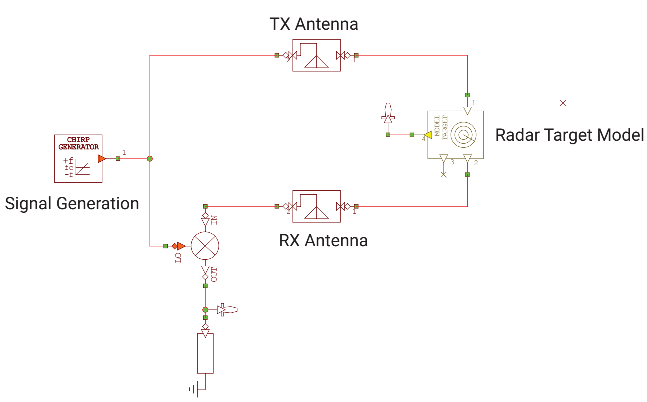

Figure 2: Basic construction of FMCW radar systems in AWR VSS software, amplifier stages (PA, LNA), and individual MIMO channels (not shown)

Figure 2 illustrates the signal being radiated between the transmit and receive antennas through a AWR VSS software radar target model that includes properties such as the radar cross section, distance, velocity, and ambient conditions. The mixer will down-convert the signal that was reflected from the target, using the swept frequency from the voltage-controlled oscillator (VCO) as the local oscillator. Taking the difference of these two signals creates a beat signal that is directly proportional to the distance to the target. This IF is fed to an analog-to-digital (A/D) converter for signal processing. This signal processing extracts the target distance using a fast Fourier transform (FFT) algorithm. By using multiple antennas, the Fourier transform also supports digital beamforming in order to produce a 2D image of the detected object.

AWR VSS software was used to study the main aspects of the MIMO radar at the system level. The software provides a block-level representation of the signal sources, LNAs, mixers, PAs, frequency multipliers, antennas, and radar targets (Figure 3) enabling the designers to tune and optimize all the key parameters and incorporate real-world operation of the radar system as more circuit-level detail was added.

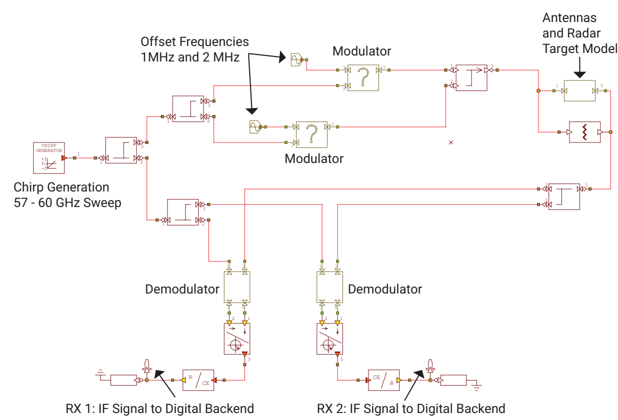

Figure 3: AWR VSS software's system diagram of the FMCW MIMO radar

The core of the radar system is the TX and RX RF integrated circuits (RFICs), both of which support four channels occupying a very small area. Additional chips can be added to the system to increase the number of channels. It is advantageous for one RFIC to support multiple channels to reduce the assembly effort and to allow scaling for a system with a very large number of channels. Separate TX and RX chips enable independent TX/RX scaling, lower the TX/RX leakage, and support closer placement to the feed structure to reduce PCB losses.

AWR Microwave Office software was used in combination with the AWR AXIEM EM analysis to design the TX and RX chips from the transistor level using the IHP SG13S SiGe PDK available for AWR software. The detailed schematic of the PA was developed using components from the foundry PDK for AWR Microwave Office software.

The passive structures were electrically large (proportionate to the wavelength) and therefore required EM analysis and optimization using the AWR AXIEM analysis. The EM components were embedded as subcircuits in the schematic for co-simulation with AWR Microwave Office software. By including EM analysis of these structures in combination with the PDK models, the measured versus simulation results for the chip-level amplifier displayed excellent agreement, as shown in Figure 4.

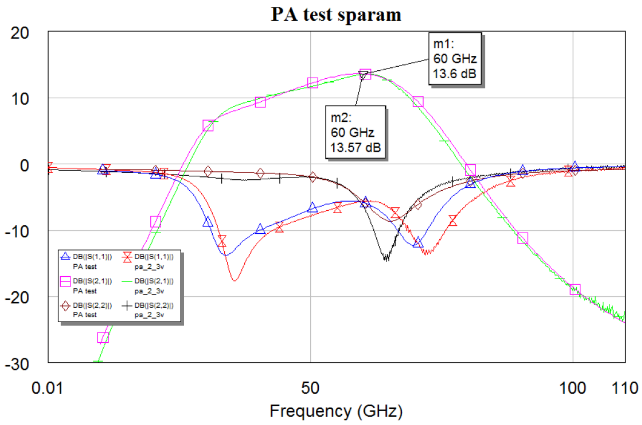

Figure 4: PA simulation and measurement results for gain and return loss

Accurate phase measurement is useful in measuring very small movements of a target, for example, in determining the heartbeat and breathing rate of a human from the displacement of the chest. The results of the radar-based multi-person heart rate variability (HRV) extraction is shown in Figure 5. Vital signs such as heart rate, HRV, and breathing can be observed from the radar signal.

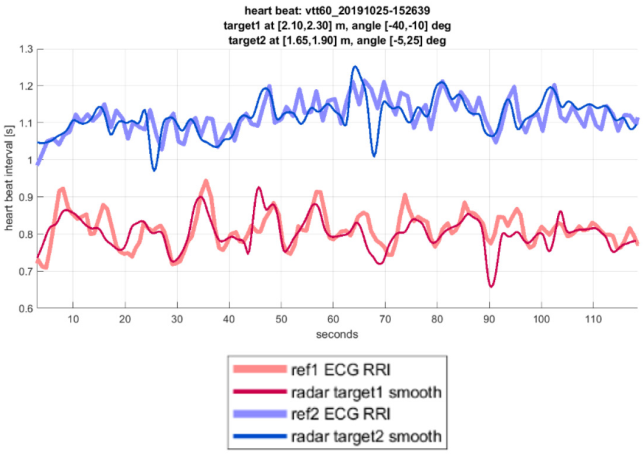

Figure 5: Results of multi-person HR and HRV extraction

Summary

VTT designers successfully designed a novel 60GHz MIMO FMCW FDM radar system using AWR software, which enabled them to develop the unique architecture and integrated circuits in such a way that the system can be scaled to much larger radar systems while still maintaining phase coherence between channels. Both 2D and 3D imaging systems were developed, and, to the best of the authors' knowledge, this is the first 3D imaging mmWave FDM MIMO radar system of its kind. AWR VSS software provided the system designers with an overall big picture and the chip designers with the simulation and design support that enabled them to focus on the complexities of implementing the mmWave RFICs.

AWR software helped us overcome the challenge of our radar system design quite well. To the best of our knowledge, this is the first 3D imaging mmWave frequency-division MIMO system of its kind."

Dr. Tero Kiuru, VTT

Register to view the "mmWave MIMO Radar System Design" webinar at www.awr.com/resource-library/mmwave-mimo-radar-system-design.